

**WHAT IS CLAIMED IS:**

1. A method for generating a test set for hard to detect faults, said method comprising:

a) identifying a set of hard to detect faults; and

b) generating the test set for the hard to detect faults by using an

5 automatic test pattern generator;

wherein, the automatic test pattern generator comprises functionality for a global generator and is adapted to consider hardware overhead and test sequence lengths, said hardware overheads being incurred when each new testcube is added to the test

10 set.

2. The method of claim 1, wherein the test set in step b is generated by a process further comprising:

(b) (i) calculating estimated cost using cost functions for each of the hard to detect faults;

5 (b) (ii) selecting a hitherto unselected target fault from the set of hard to detect faults that has a minimum cost;

(b) (iii) generating a testcube for the selected target fault;

(b) (iv) comparing real cost with estimated cost for the selected hard fault;

10 (b) (v) if the real cost is greater than a sum total of the estimated cost plus a predetermined error, performing an appropriate one of the following sub-steps:

- (1) if there are still unselected faults in the set of hard to detect faults, returning to step (b) (ii); or
  - 15 (2) if no unselected faults remain in the set of hard to detect faults, selecting a testcube having a minimum real cost;
- (b) (vi) if real cost is not greater than a sum total of the estimated cost plus the predetermined error, retaining the test cube generated in step (b) (iii) as the selected test cube;
- 20 (b) (vii) marking all faults detected by the selected test cube; and
- (b) (viii) adding the selected test cube into a current test set and updating a current generator.

3. The method of claim 2 wherein said cost functions comprises of controllability costs, observability costs and test generation costs.

4. The method of claim 2 wherein in step (b) (iii) a number of specified inputs for the testcube are minimized by bit stripping.

5. The method of claim 3 wherein the controllability cost for an input is calculated based on the following formulae:

$$Cv(p_k) = \begin{cases} 0 & \text{if } g_k^i = U \\ 0 & \text{if } g_k^i = v \\ w & \text{if } g_k^i = \bar{v} \quad (\text{where } w \gg 1) \\ 1 & \text{if } g_k^i = X \text{ and } gg_k = B \\ 1 & \text{if } g_k^i = X \text{ and } gg_k = v \\ h & \text{if } g_k^i = X \text{ and } gg_k = \bar{v} \quad (\text{where } h \gg 1) \\ h & \text{if } g_k^i = X \text{ and } gg_k = N \end{cases}$$

where v is a binary value, 0 or 1, X is a don't care input,

5 Cv (p<sub>k</sub>) represents cost for an input p<sub>k</sub>,

g<sub>k</sub> is an input in the current generator, and

gg<sub>k</sub> represents an input in the global generator, and wherein

the controllability cost of each input is used to estimate a number of input conflicts and overriding signals that would be created

10 by setting a line to a binary value v.

6. The method of claim 3 wherein the controllability costs is calculated based on the following formulae:

a controllability cost for an internal circuit line  $l$  in the circuit, is

$$Cv(l) = \begin{cases} \min_{l_a} \{Cc(l_a)\} & \text{if } v = c \oplus i \\ \sum_{l_a} C\bar{c}(l_a) & \text{otherwise,} \end{cases}$$

where  $l_a$  and  $l$  are respectively the inputs and the output of a gate with controlling value  $c$  and inversion  $i$ .

7. The method of claim 3, wherein the test generation cost is a sum of cost to activate a specific fault on a line and a cost of propagating the fault through the line.

8. A method of generating test sets for a fault list comprising hard to detect faults, the method comprising:

- (a) initializing  $i \leftarrow 0$  and  $glob\_gen \leftarrow \{N, N, \dots, N\}$ ;
- (b) initializing a current testcube set,  $C^i \leftarrow \phi$ ;
- (c) unmarking all faults in the fault list;
- (d) initializing a current generator,  $gen(C^i) = \{X, X, \dots, X\}$  and  $j \leftarrow 0$ ;
- (e) if there are no more faults in the fault list, then proceeding to step (m);

- (f) generating a testcube  $c^j$  using an ATPG;
- 10 (g) adding the testcube  $c^j$  to a current testcube set,  $C^i \leftarrow C^i \cup c^j$ ;
- (h) mark faults detected by the testcube  $c^j$ ;
- (i) setting  $j \leftarrow j + 1$ ;
- (k) if the number of conflicting inputs of any testcube in  $C^i$  is greater than a positive integer  $M$  then  $C^i \leftarrow C^i - c^j$ ,  $i \leftarrow i + 1$ , updating the
- 15 global generator, and proceeding to step (b);
- (l) if the number of conflicting inputs of any testcube in  $C^i$  is not greater than  $M$ , updating  $gen(C^i)$  and proceeding to step (e);
- (m) generating 3-weight weighted random pattern testing (WRPT) patterns by fixing inputs or applying pure random patterns to inputs
- 20 according to  $gen(C^i)$ ; and
- (n) running fault simulation to drop the faults that are detected by the generated 3-weight WRPT patterns.

9. The method of claim 8, further comprising:

(o) merging compatible overriding signals.

10. The method of claim 8, wherein said generating a test cube in step (f) is done by a process comprising:

- \*      \*
- (f) (i) calculating estimated cost using cost functions for each of the hard to detect faults;
- 5    (f) (ii) selecting a hitherto unselected target fault from the set of hard to detect faults that has a minimum cost;
- (f) (iii) generating a testcube for the selected target fault;
- (f) (iv) comparing real cost with estimated cost for the selected hard fault;
- 10   (f) (v) if the real cost is greater than a sum total of the estimated cost plus a predetermined error, performing an appropriate one of the following sub-steps:
- (1) if there are still unselected faults in the set of hard to detect faults, returning to step (f) (ii); or
- 15    (2) if no unselected faults remain in the set of hard to detect faults, selecting a testcube having a minimum real cost;
- (b) (vi) if real cost is not greater than a sum total of the estimated cost plus the predetermined error, retaining the test cube generated in step (f) (iii) as the selected test cube;
- 20   (f) (vii) marking all faults detected by the selected test cube; and
- (f) (viii) adding the selected test cube into a current test set and updating the current generator.

11. The method of claim 10, wherein inversely compatible inputs are merged by additionally inverting a signal before being fed to a gate.

12. The method of claim 10 wherein the controllability cost for an input is calculated based on the following formulae:

$$Cv(p_k) = \begin{cases} 0 & \text{if } g_k^i = U \\ 0 & \text{if } g_k^i = v \\ w & \text{if } g_k^i = \bar{v} \quad (\text{where } w \gg 1) \\ 1 & \text{if } g_k^i = X \text{ and } gg_k = B \\ 1 & \text{if } g_k^i = X \text{ and } gg_k = v \\ h & \text{if } g_k^i = X \text{ and } gg_k = \bar{v} \quad (\text{where } h \gg 1) \\ h & \text{if } g_k^i = X \text{ and } gg_k = N \end{cases}$$

where v is a binary value, 0 or 1, X is a don't care input,

Cv (pk) represents cost for an input pk,

5 gk is an input in the current generator, and

ggk represents an input in the global generator, and wherein

the controllability cost of each input is used to estimate a number of input conflicts and overriding signals that would be created by setting a line to a binary value v.

13. The method of claim 10 wherein the controllability costs is calculated based on the following formulae:

a controllability cost for an internal circuit line 1 in the circuit, is

$$Cv(l) = \begin{cases} \min_{l_a} \{Cc(l_a)\} & \text{if } v = c \oplus i \\ \sum_{l_a} C\bar{c}(l_a) & \text{otherwise,} \end{cases}$$

where  $l_a$  and  $l$  are respectively the inputs and the output of a  
5 gate with controlling value  $c$  and inversion  $i$ .

14. The method of claim 10, wherein the test generation cost is a sum of cost to activate a specific fault on a line and a cost of propagating the fault through the line.

15. A parallel type test per scan built-in self test circuit comprising:

a circuit under test comprising inputs;

a set of scan flip flops that are connected to the inputs, each of  
5 said scan flip flops having at least a synchronous reset (R) or a synchronous preset (S) pin ;

a LFSR for loading random vectors that provide input to the set of scan flip-flops;

a decoder providing decoder outputs, wherein said decoder  
10 outputs control the R and S pins in the scan flip-flops, said decoder comprising a functionality of a global generator;



a counter providing inputs to the decoder that determine a state of the decoder outputs; and

an enable input for the decoder,

- 15 wherein the decoder provides overriding signals to by controlling the input to the R and S pins, said overriding signals overriding the random vectors based on tests in a generator for test patterns for hard faults, said tests being generated by an automatic test pattern generator.

16. The circuit of claim 15 wherein the enable is provided by an AND gate, that performs an AND operation on a override enable input signal and a last scan input signal.

17. The circuit of claim 16, wherein random patterns are overridden and the BIST enabled by providing a 1 input to the override enable input signal.

18. The circuit of claim 16, wherein the last scan input signal is set to a 1 only at a last cycle of each scan shifting operation.

19. The circuit of claim 15, wherein the counter being adapted to be set to 0 initially and maintained at 0 while a specific

number (T) of random patterns are input, said random patterns being modified based on the generator provided by the decoder, said counter  
5 being further adapted to be incremented and T random patterns applied with a new generator, said increment being repeated until all generators have been applied by the decoder.

20. The circuit of claim 15, wherein compatible overriding signals that can be merged are driven by a same output signal of the decoder, thereby reducing a number of decoder outputs.

21. The circuit of claim 15, wherein inversely compatible overriding signals are driven by a decoder output directly and the same decoder output after passing through an inverter.

22. The circuit of claim 15, wherein if a scan input is assigned a 1 by the global generator, then the corresponding scan flip-flop has an S pin.

23. The circuit of claim 15, wherein if a scan input is assigned a 0 by the global generator, then the corresponding scan flip-flop has an R pin.

24. The circuit of claim 15, wherein if a scan input is assigned both a 0 and 1 by the global generator, then the corresponding scan flip-flop has both R and S pins.

25. The circuit of claim 15, wherein if a scan flip-flop already has a high active S pin and whose corresponding scan input is assigned a 1 in the global generator, then a two input OR gate is inserted between the S pin and a normal present signal.

26. The circuit of claim 15, wherein if a scan flip-flop already has a high active R pin and whose corresponding scan input is assigned a 0 in the global generator, then a two input OR gate is inserted between the S pin and a normal present signal.

27. The circuit of claim 15, wherein if a scan flip-flop already has a low active S pin and whose corresponding scan input is assigned a 1 in the global generator, then a two input AND gate is inserted between the S pin and a normal present signal.

28. The circuit of claim 15, wherein if a scan flip-flop already has a low active R pin and whose corresponding scan input is assigned

a 0 in the global generator, then a two input AND gate is inserted between the S pin and a normal present signal.

29. A serial type test per scan built-in self-test circuit comprising:

- a circuit under test comprising inputs;
- a set of scan flip flops that are connected to the inputs;
- 5 a LFSR for loading random vectors that provide input to the set of scan flip-flops;
- an AND gate and an OR gate inserted between said LFSR and the set of scan flip flops;
- a decoder providing two decoder output signals  $D_0$  and  $D_1$ , said
- 10 decoder output signals being input to the AND and OR gates;
- a generator counter that selects a generator providing inputs to the decoder;
- a scan counter that provides input to the decoder, wherein a state of the decoder outputs are together determined by the counter
- 15 input and the scan counter input; and
- an enable input for the decoder,
- wherein the decoder provides overriding signals, said overriding signals overriding the random vectors based on tests in a generator for

test patterns for hard faults, said tests being generated by an  
20 automatic test pattern generator.

30. The circuit of claim 29, wherein area overhead of the decoder is reduced by inserting toggle flip-flops between the two outputs of the decoder and inputs to the AND and OR gates.

31. The circuit of claim 29, wherein inputs from the random vector corresponding to conflicting inputs in the generator are not overridden.

32. The circuit of claim 29, wherein the scan\_counter is adapted to increase by 1 at every positive edge of a scan clock and new values for scan inputs are scanned in serially until inputs corresponding to all pins have been scanned in,

5 wherein if a value in a generator is a 1, a 1 is scanned in as a scan input in a corresponding pin, instead of a value provided by the random vector, and

if a value in the generator is a 0, a 0 is scanned in as a scan input in a corresponding pin, instead of a value provided by the  
10 random vector and

if a value in the generator is a don't care or a conflicting value,  
then a value in the random vector is scanned in.

33. The circuit of claim 30, wherein an order of scanning is determined by using genetic algorithms, wherein a permutation of scan elements in the scan chain is used as a genetic code, and the genetic algorithm is used to determine an order of scan elements that  
5 leads to a minimum number of minterms.

34. The circuit of claim 33 wherein compatible overriding signals are merged prior to applying genetic algorithms.

35. The circuit of claim 34, wherein scan inputs in a group of compatible scans are rearranged to satisfy routing or load capacity.